

AD695507

NOISE EXPOSURE FORECAST CONTOUR INTERPRETATIONS
OF AIRCRAFT NOISE TRADEOFF STUDIES

TECHNICAL REPORT
FAA-NO-69-2
MAY 1969

by
Dwight E. Bishop
Richard D. Horonjeff

Bolt Beranek and Newman Inc.
15808 Wyandotte Street
Van Nuys, California 91406

Prepared for
Department of Transportation
Federal Aviation Administration
Office of Noise Abatement

Under Contract FA68WA-1900

This report has been approved for general availability. The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policy of the FAA. This report does not constitute a standard, specification, or regulation.

ABSTRACT

The relative effectiveness of several changes in aircraft operating procedures and aircraft hardware in reducing noise exposure near airports were rated by determining the relative changes in land areas falling within the Noise Exposure Forecast 30 and 40 contours. Sets of NEF contours were constructed for two different mixes of aircraft types operating from a single runway airport; the number of operations per day was varied from 200 to 1000. The changes included power cutbacks after takeoff, two segment approaches and retrofit of four-engine turbofan aircraft with acoustically-lined nacelles or with a "quiet engine". There was a significant reduction in land area exposed to NEF 30 or 40 noise environments by the introduction of either lined nacelles or quiet engines. Operational changes alone generally resulted in moderate reductions (and even some increases) in the land areas falling within the NEF 30 or 40 contours. The relative effectiveness of the changes did not vary appreciably with the number of operations.

TABLE OF CONTENTS

	<u>Page No.</u>
LIST OF TABLES	v
LIST OF FIGURES	vi
I. INTRODUCTION	1
II. STUDY APPROACH AND ASSUMPTIONS	4
A. Noise Exposure Forecast Procedures	4
B. Aircraft Noise And Performance Characteristics	5
III. ANALYSIS PROCEDURE	15
A. Airport Operations	15
B. Runway Utilization	17
C. NEF Area Calculations	17
IV. TRADEOFF STUDY COMPARISONS	20
A. Operational Changes	31
B. Equipment Changes	31
C. Comparison of Operational And Equipment Changes	32
D. Variations With Total Number Of Operations	32
E. Major Trends	35
REFERENCES	
APPENDIX	

LIST OF TABLES

<u>Table No.</u>		<u>Page No.</u>
I	LIST OF CHANGES IN OPERATIONS AND AIR- CRAFT CHARACTERISTICS	2
II	BASIC ASSUMPTIONS FOR TAKEOFF PROFILE DISTANCES AND NOISE REDUCTION DUE TO THRUST CUTBACK AFTER TAKEOFF	6
III	REDUCTION IN APPROACH LEVELS FOR 6° GLIDE SEGMENT	7
IV	CHANGES IN NOISE LEVELS DUE TO ACOUS- TICALLY LINED NACELLES FOR FOUR-ENGINE TURBOFAN AIRCRAFT	8
V	REDUCTION IN EFFECTIVE PERCEIVED NOISE LEVELS PRODUCED BY FOUR-ENGINE TURBOFAN AIRCRAFT RETROFITTED WITH "QUIET" ENGINES	9
VI	AIRCRAFT MIX FOR TRADEOFF STUDIES	16
VII	LAND AREAS WITHIN NEF 30 AND NEF 40 CONTOURS	18
VIII	RELATIVE AREAS OF LAND WITHIN NEF CONTOURS FOR VARIOUS CHANGES IN AIR- CRAFT OR OPERATING PROCEDURES	21
IX	SUMMARY OF SOME COMPARISONS FROM NEF TRADEOFF STUDY	22

LIST OF FIGURES

<u>Figure No.</u>		<u>Page No.</u>
1	VARIATION IN EFFECTIVE PERCEIVED NOISE LEVELS WITH DISTANCE FOR VARIOUS AIRCRAFT CLASSES - TAKEOFF POWER	10
2	VARIATION IN EFFECTIVE PERCEIVED NOISE LEVELS WITH DISTANCE FOR VARIOUS AIRCRAFT CLASSES - APPROACH POWER	11
3	GENERALIZED TAKEOFF PROFILES	12
4	VARIATION IN PERCEIVED NOISE LEVELS WITH DISTANCE FOR FOUR-ENGINE TURBOFAN AIRCRAFT RETROFITTED WITH NASA QUIET ENGINE	13
5	AIRCRAFT FLIGHT PROFILE MODIFICATIONS . .	14
6	SKETCH OF RUNWAY AND FLIGHT PATH CONFIGURA- TIONS	19
7	SAMPLE OF NEF CONTOURS - AIRCRAFT MIX A .	25
8	RELATIVE LAND AREAS WITHIN NEF 30 AND NEF 40 CONTOURS - TAKEOFF (NORTH) SECTOR - 100 TAKEOFFS PER DAY	26
9	RELATIVE LAND AREAS WITHIN NEF 30 AND NEF 40 CONTOURS - LANDING (SOUTH) SECTOR - 100 LANDINGS PER DAY	27
10	RELATIVE LAND AREAS WITHIN NEF 30 AND NEF 40 CONTOURS - COMBINED TAKEOFF AND LANDING OPERATIONS - 100 TAKEOFFS AND 100 LANDINGS PER DAY	28

LIST OF FIGURES (Con't)

<u>Figure No.</u>		<u>Page No.</u>
11	RELATIVE LAND AREAS WITHIN NEF 30 AND NEF 40 CONTOURS - TAKEOFF (NORTH) SEC- TOR - VARIABLE NUMBER OF TAKEOFFS . . .	29
12	RELATIVE LAND AREAS WITHIN NEF 30 AND NEF 40 CONTOURS - LANDING (SOUTH) SEC- TOR - VARIABLE NUMBER OF LANDINGS . . .	30
13	VARIATION IN TAKEOFF SECTOR LAND AREAS WITHIN NEF 30 AND NEF 40 CONTOURS WITH NUMBER OF TAKEOFFS	33

I. INTRODUCTION

This report summarizes the results of initial aircraft noise reduction tradeoff studies conducted in performance of Tasks I and II under Phase III of FAA contract FA68WA-1900. These tasks included the definition of various aircraft noise parameter modifications and application of these modifications to a simplified airport situation in order to evaluate the relative significance of changes in aircraft noise characteristics of operational procedures on the areas enclosed within Noise Exposure Forecast (NEF) contours. The results of the study are to aid in the selection of various noise parameter modifications which are to be later applied in developing and comparing NEF contours for Los Angeles International Airport, O'Hare International Airport and J.F. Kennedy International Airports for the 1975 time period.*

A relatively simple airport situation was assumed, based upon a single runway, Runway 1-19, 10,000 feet in length. For this single runway, with assumed straight-out departure and straight-in landing flight paths, differences in land areas falling within NEF contours resulting from changes in aircraft operations or aircraft characteristics were determined. The changes studied included power cutbacks after takeoff, two segment approaches and retrofit of four-engine turbofan aircraft with acoustically lined nacelles, or with a "quiet" engine, now under development by NASA. Table I lists the changes in more detail.

NEF contours were determined for two mixes of aircraft types. Most contours were developed on the basis of 100 takeoffs and 100 landings per day (i.e. 200 operations per day) with more limited study of the NEF contours resulting from 200 and 500 takeoffs and landings per day. The study was not intended to exhaustively cover all possible modifications that might be considered.

* As specified under Task III, Phase III of FAA contract FA68WA-1900.

TABLE I
LIST OF CHANGES IN OPERATIONS
AND AIRCRAFT CHARACTERISTICS

- Condition A: Power cutback after takeoff -- A power cutback to a 3% climb gradient at a distance of 3.5 nautical miles from start of takeoff roll, or, a cutback to a 3% climb gradient at an altitude of 1000 ft if the aircraft cannot gain 1000 ft altitude at 3.5 nautical miles from start of takeoff roll.
- Condition A-1: Condition A applied only to four-engine aircraft.
- Condition B: Power cutback after takeoff -- A power cutback to a 6% climb gradient at a distance of 3.5 nautical miles from start of takeoff roll, or, a power cutback to a 6% climb gradient at an altitude of 1000 ft if the aircraft cannot reach 1000 ft altitude at 3.5 nautical miles from start of takeoff roll.
- Condition B-1: Condition B applied only to four-engine aircraft.
- Condition C: A 6°/3° glide path approach -- The aircraft descends at a 6° glide angle until reaching 3.0 nautical miles from the runway threshold at which time the glide angle is changed to 3°.
- Condition C-1: Condition C applied only to turbofan aircraft.
- Condition D: Retrofit of acoustically lined nacelles to four-engine turbofan aircraft.
- Condition D-1: Minimum treatment.
- Condition D-2: Maximum treatment
- Condition E: Retrofit of four-engine turbofan aircraft with a "quiet" engine, currently under study by NASA.

Section II outlines the study approach and basic assumptions employed in the study. Section III outlines the analysis procedure. Section IV presents some tradeoff study comparisons and summarizes the major trends evident from the study.

II. STUDY APPROACH AND ASSUMPTIONS

A. Noise Exposure Forecast Procedures

Noise Exposure Forecast (NEF) procedures have been developed in the parallel studies of references 1 and 2. The procedures in this report follow closely those of reference 1.* Basically, the NEF procedures provide estimates of the total noise environment arising from the multiple operations of aircraft during take-off and landing operations in the vicinity of an airport. The NEF values are calculated from knowledge of: (a) measures of the aircraft flyover noise described in terms of the Effective Perceived Noise Level (EPNL), expressed in EPNdB; and (b) the average number of flyovers per daytime and per nighttime periods. For convenience, the basic equations for calculating the NEF values at a ground position are given in the Appendix.

One of the major applications of the NEF procedures is in comparing the noise environment near an airport for both current and expected future conditions and to examine the effects on land use of changes in modes of operations or mixes of aircraft. In these circumstances one must consider the effect of numbers of operations of different types of aircraft. Since one is concerned in determining the total noise exposure resulting from the operation of a number of aircraft of various characteristics, trip lengths, etc. precise descriptions of aircraft noise and aircraft performance may be replaced by approximations. Hence generalized descriptions of aircraft noise in terms of EPNL vs distance curves and generalized aircraft takeoff and landing profiles will usually be adequate.

Interpretations of the NEF values in terms of expected influence on various land uses and expected community response are given in references 1 and 2. In this report, contours of NEF 30 and 40 values are given. These define the three Noise Exposure Forecast areas described in Table II of reference 1.

* Currently, Committee A-21 of the Society of Automotive Engineers is reviewing the NEF procedure of reference 1 and 2 for the purpose of recommending a common procedure use. For the purposes of the current study, differences in calculation procedures between those discussed in this report and those under consideration by the SAE are not likely to be large.

B. Aircraft Noise And Performance Characteristics

In this study the major aircraft classifications and the noise and takeoff and landing profile characteristics for these classifications are the same as utilized in reference 1. Figures 1 and 2 present the EPNL vs distance characteristics for air-to-ground sound propagation. Figure 1 shows the takeoff characteristics while Fig. 2 shows the approach characteristics.* Figure 3 shows the basic takeoff profiles assumed in the study.

The estimates for the four-engine turbofan aircraft retrofitted with the "quiet" engine are based upon perceived noise level estimates provided by NASA, reference 3, and further interpreted by BBN for the purposes of this study. The perceived noise level (PNL) vs distance curves assumed for the quiet engine are shown in Fig. 4.

Table I lists the changes introduced in the study; Fig. 5 illustrates the changes in profiles introduced by the power cutback after takeoff, and by the two segment approach. Tables II through V lists the changes in noise levels assumed for the various conditions listed in Table I. Table II lists the reduction in noise level assumed due to power cutback after takeoff (conditions A and B of Table I). Table III lists the reduction in approach noise for a 6 degree glide slope compared to a 3 degree glide slope (condition C). Table IV lists the changes in noise levels assumed due to retrofit of acoustically-lined nacelles to large four-engine turbofan aircraft (condition D). Two degrees of effectiveness in the nacelle treatment were assumed. The change in effective perceived noise levels assumed for the quiet engine retrofit (condition E) is summarized in Table V. (These values were obtained from comparison of the curves given in Figs. 1 and 2.) A change in takeoff performance was also assumed with the engine retrofit, resulting from an increase in thrust for the quiet engine.

* SAE Committee A-21 is reviewing available noise information and revised EPNL vs distance curves have recently been developed. These characteristics will be used in future NEF studies. However the differences in noise data would not result in major changes in the findings presented in this report.

TABLE II
BASIC ASSUMPTIONS FOR TAKEOFF PROFILE DISTANCES AND
NOISE REDUCTION DUE TO THRUST CUTBACK AFTER TAKEOFF

Aircraft Classification	Takeoff Profile Distance (See Fig. 5)		Noise Reduction in EPNdB (1)	
	A	B	CL. Grad.	
	Naut. Miles	Ft.	After C/B	
			3%	6%
Four-engine Turbojet				
Short Range	3.5	2300	8	6
Long Range	3.5	1130	7	4
Four-engine Turbofan				
Short Range				
Standard	3.5	2300	2	1
Stretched	3.5	2300	2	1
SO. AB. TR. (Min)	3.5	2300	3	2
SO. AB. TR. (Max)	3.5	2300	4	3
Quiet Engine	3.5	2300	5	4
Jumbo	3.5	2300	7	6
Long Range				
Standard	3.5	1130	1	1
Stretched	3.5	1130	1	1
SO. AB. TR. (Min)	3.5	1130	2	1
SO. AB. TR. (Max)	3.5	1130	3	2
Quiet Engine	3.5	2300	5	4
Jumbo	4.0	1000	6	4
Two- and Three-engine Turbofan				
Short & Long Range				
Standard	3.5	2650	8	6
Stretched	3.5	2650	5	4

(1) Relative to values for takeoff thrust and assumed constant over profile segment beginning at C in Fig. 5.

TABLE III
REDUCTION IN APPROACH LEVELS FOR 6° GLIDE SEGMENT*

Large Four-engine Turbojet Transports	3 EPNdB
Large Four-engine Turbofan Transports Standard and Stretched	1
Nacelle Treatment (minimum or maximum)	3
Quiet Engine Retrofit	4
Two- and Three-Engine Turbofan Transports	3
Large Four-engine Jumbo Turbofan Transports	3

* These reductions apply to EPNL values assumed for conventional (3° glide slope) approaches and are assumed constant over profile segment E-F of Fig. 5.

TABLE IV
CHANGES IN NOISE LEVELS DUE TO ACOUSTICALLY LINED
NACELLES FOR FOUR-ENGINE TURBOFAN AIRCRAFT

	<u>Min. Lining</u>		<u>Max. Lining</u>	
	<u>T/O</u>	<u>L</u>	<u>T/O</u>	<u>L</u>
PNL	2	6	2	8
Pure-Tone Correction	2	2	3	4
EPNL	4	8	5	12

Note: As noted in Table II, with linings installed, an additional reduction in effective perceived noise levels due to power cutback after takeoff occurs, as follows:

	<u>Min. Lining</u>		<u>Max. Lining</u>	
Cutback				
To 3% C.G.				
Short Range	3	EPNdB	4	EPNdB
Long Range	2		3	
Cutback				
To 6% C.G.				
Short Range	2		3	
Long Range	1		2	

TABLE V
REDUCTION IN EFFECTIVE PERCEIVED NOISE LEVELS PRODUCED
BY FOUR-ENGINE TURBOFAN AIRCRAFT RETROFITTED
WITH "QUIET" ENGINES

	Slant Distance, Ft.		
	<u>400</u>	<u>1000</u>	<u>4000</u>
Takeoff	25 EPNdB	22 EPNdB	14.5 EPNdB
Approach	28	25	16.5

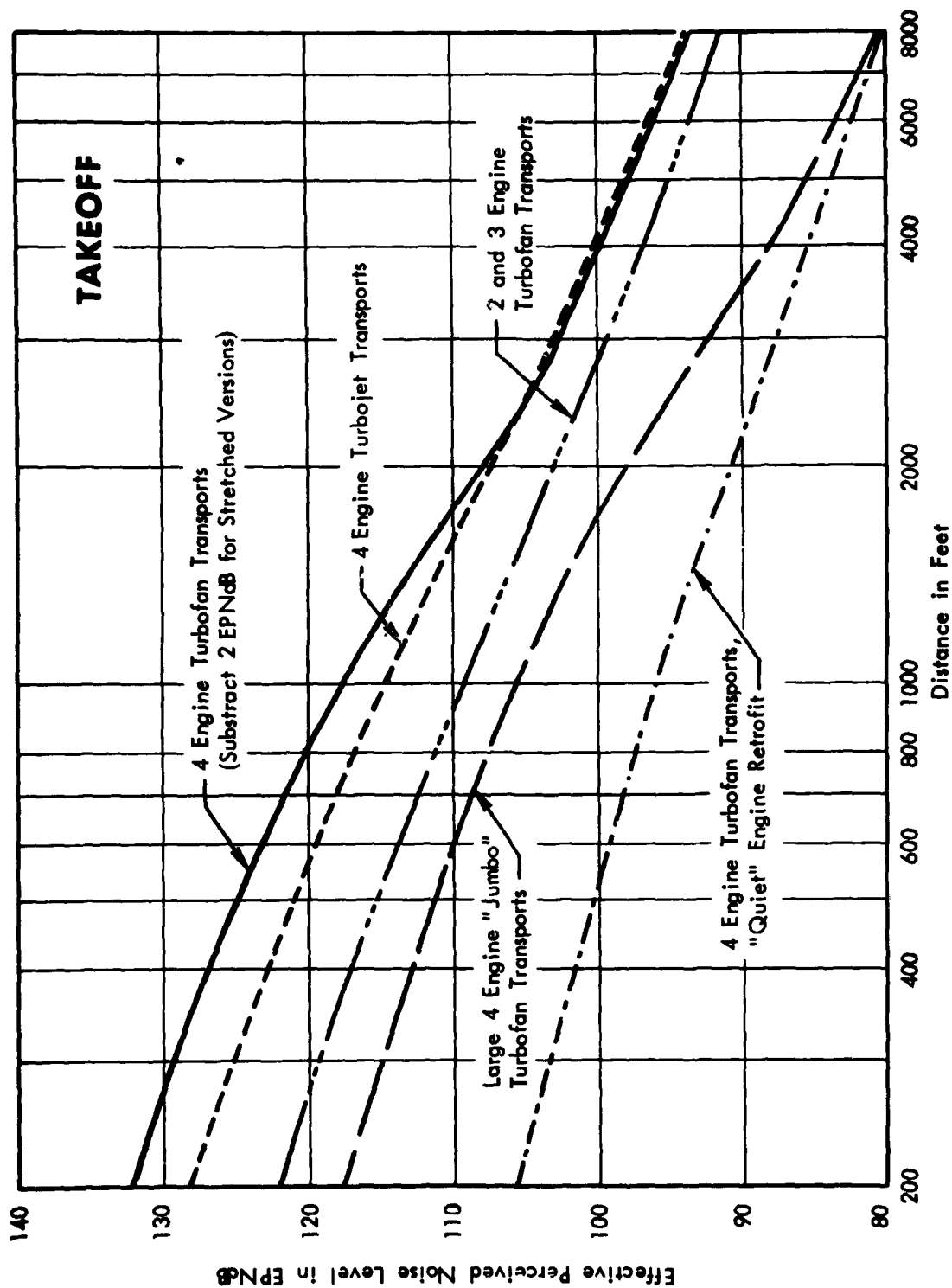


FIGURE 1. VARIATION IN EFFECTIVE PERCEIVED NOISE LEVELS WITH DISTANCE FOR VARIOUS AIRCRAFT CLASSES - TAKEOFF POWER

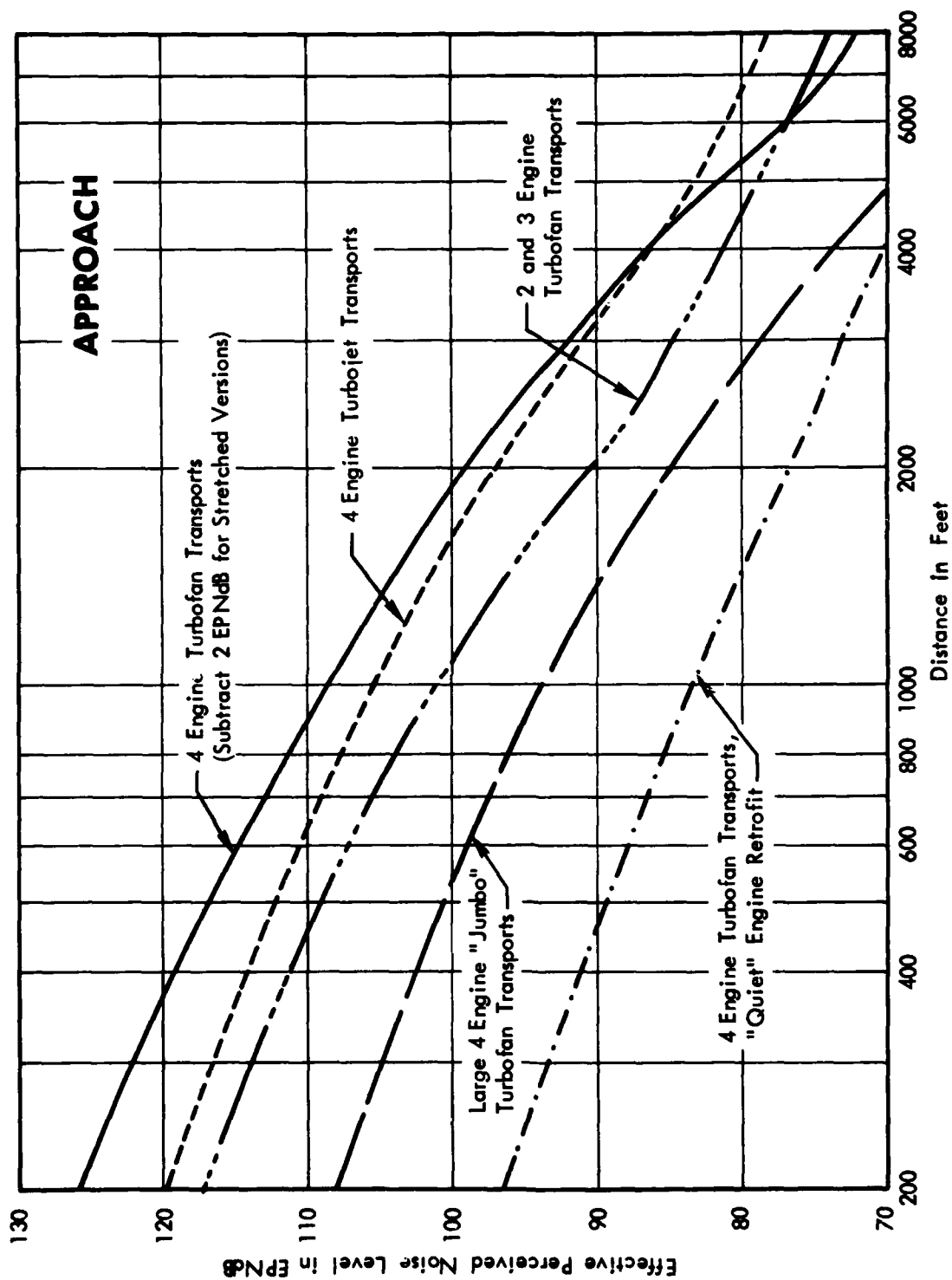


FIGURE 2. VARIATION IN EFFECTIVE PERCEIVED NOISE LEVELS WITH DISTANCE FOR VARIOUS AIRCRAFT CLASSES - APPROACH POWER

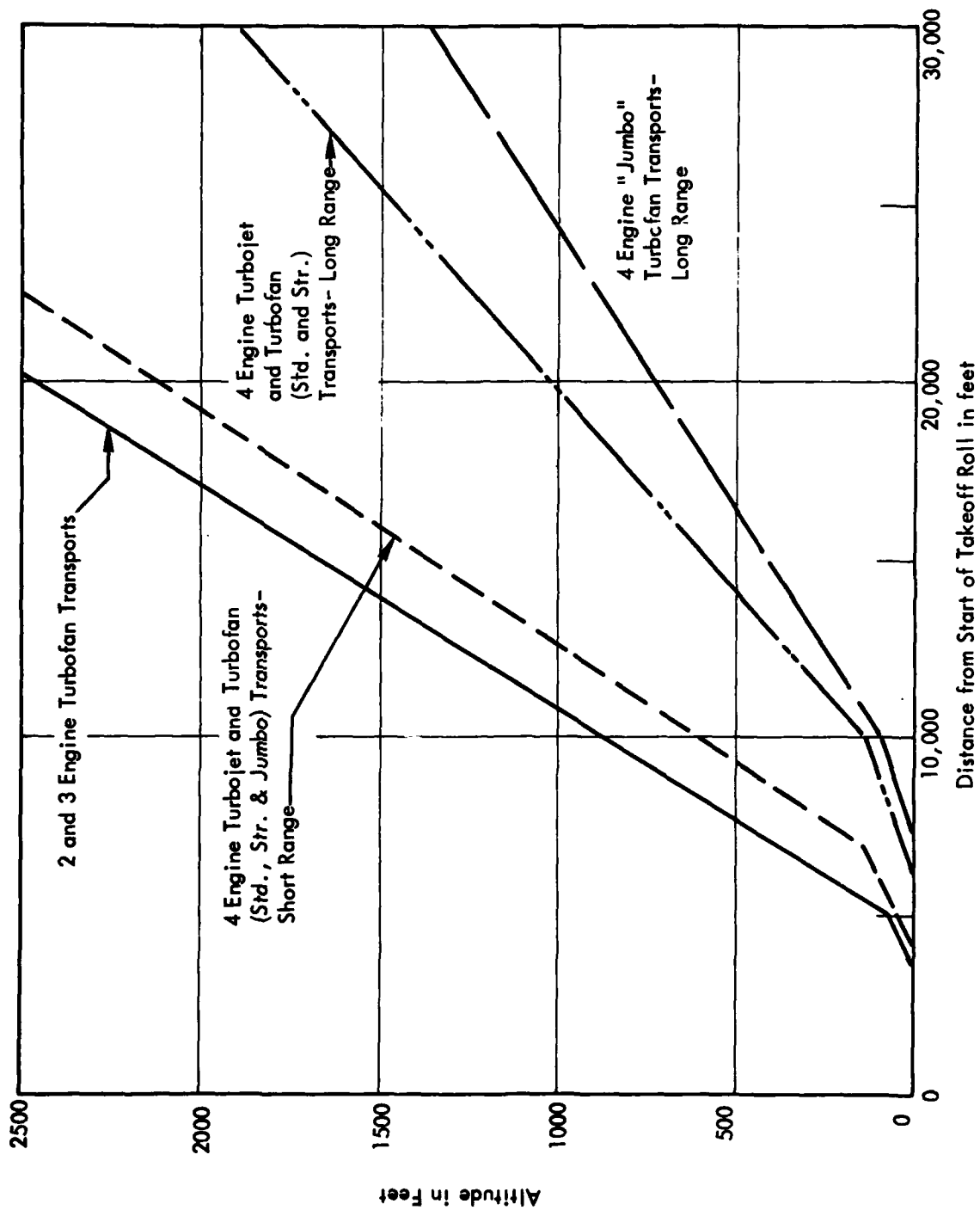


FIGURE 3. GENERALIZED TAKEOFF PROFILES

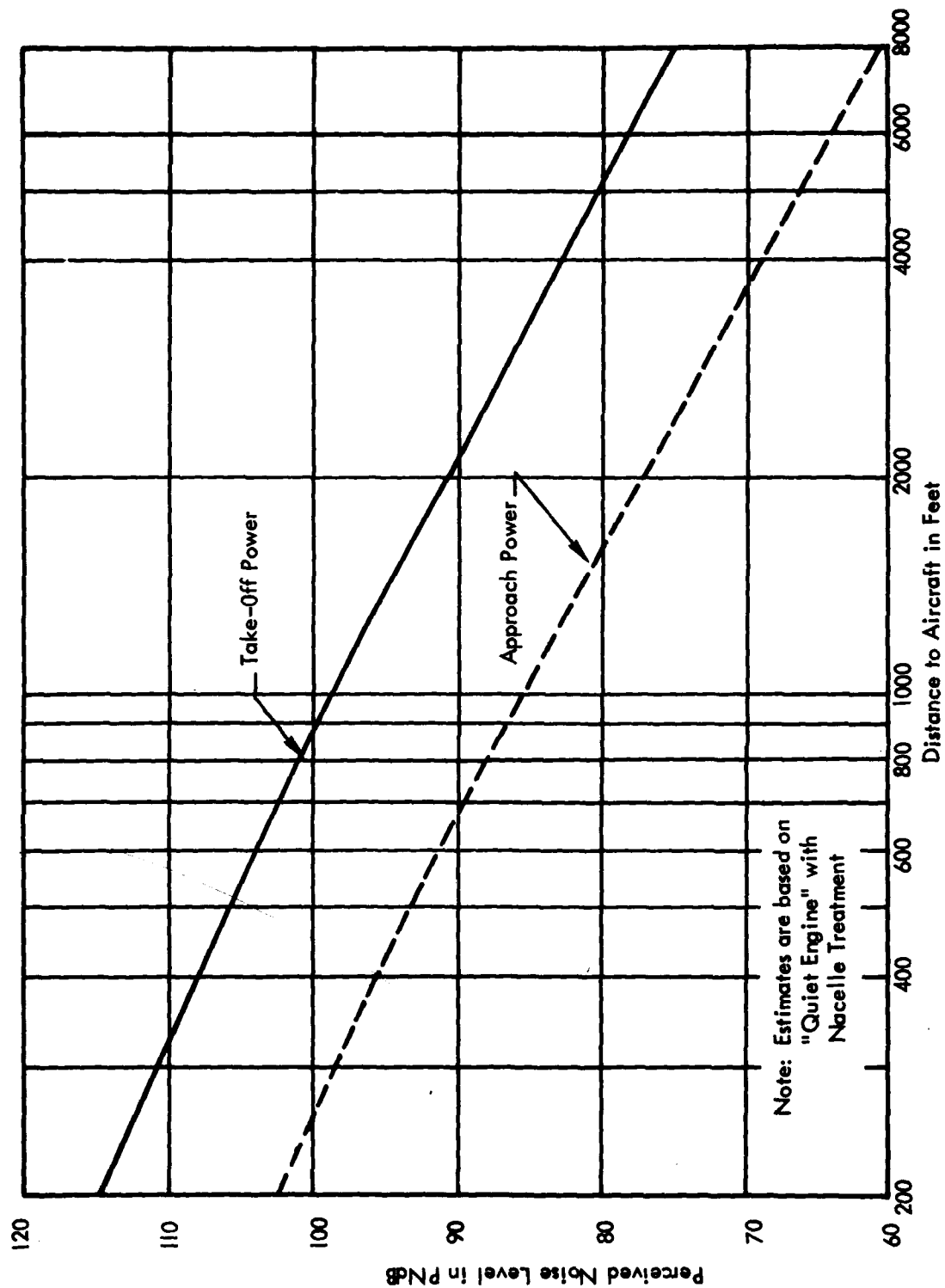
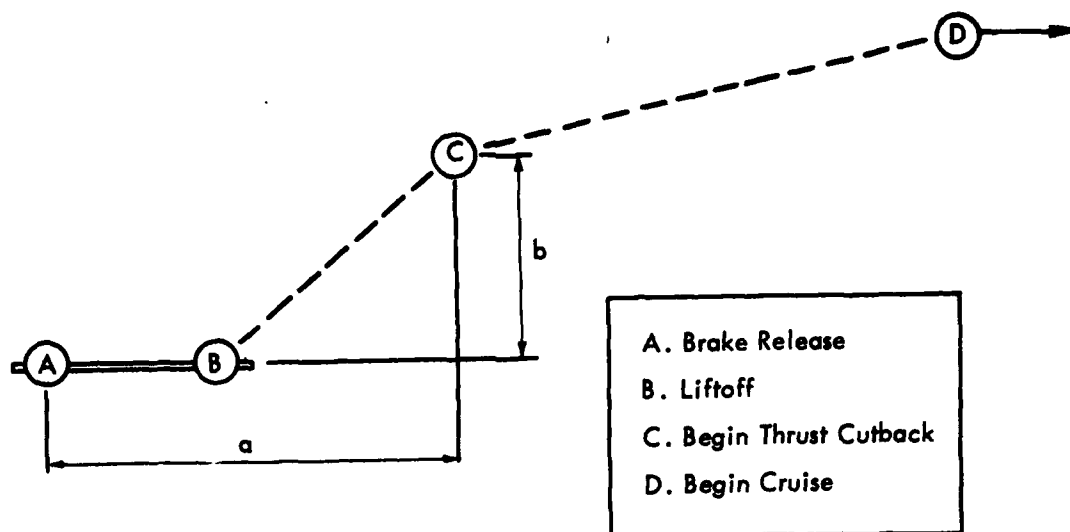
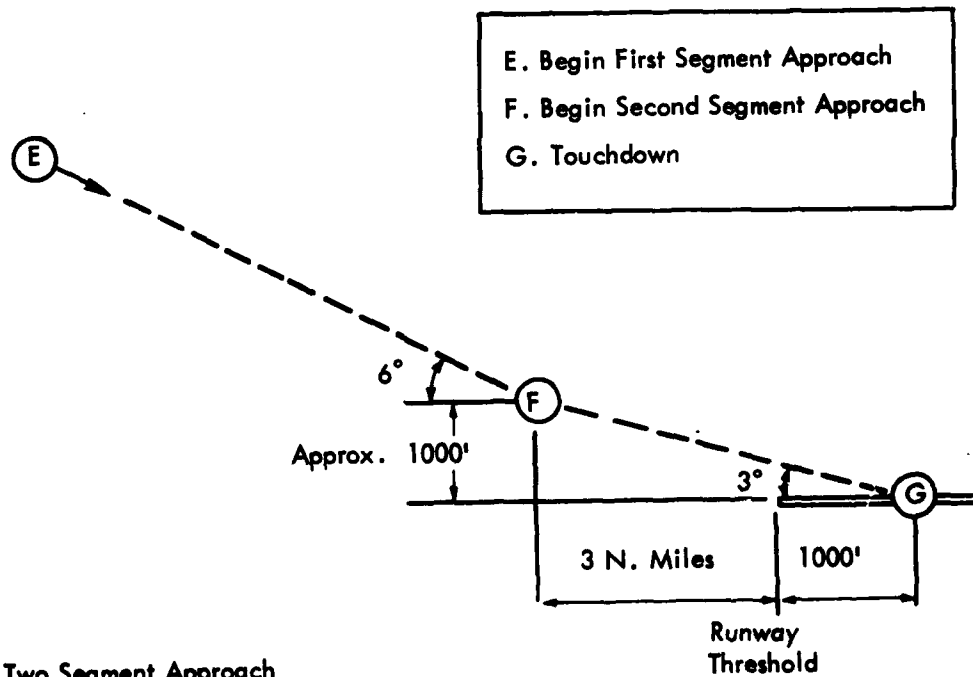


FIGURE 4. VARIATION IN PERCEIVED NOISE LEVELS WITH DISTANCE FOR FOUR ENGINE TURBOFAN AIRCRAFT RETROFITTED WITH NASA QUIET ENGINE



(a) Thrust Cutback After Takeoff



(b) Two Segment Approach

FIGURE 5. AIRCRAFT FLIGHT PROFILE MODIFICATIONS

III. ANALYSIS PROCEDURE

A. Airport Operations

The Noise Exposure Forecast value at a particular ground point near an aircraft flight path is dependent upon the noise levels produced by the different types of aircraft and the number of operations (per day) of each type of aircraft that generate these levels. The sizes and shapes of the NEF contours are dependent upon the total number of flights per day and the proportions of aircraft types making-up the total number of operations. Thus, the changes in NEF contours produced by a given change in aircraft characteristics will be dependent upon both the volume of operations and the various proportions of aircraft making-up the total aircraft mix.

In this study, two different aircraft mixes were chosen. The proportion of aircraft in the two mixes are listed in Table VI. Mix A has a relatively high proportion of two- and three-engine turbofan aircraft and a significant proportion of large four-engine turbofan aircraft operating at relatively short ranges (less than 2000 nautical miles). It is representative of the mix of aircraft at large midcontinent airports--Chicago O'Hare Airport, for example. Mix B includes a relatively high proportion of large four-engine turbofan aircraft operations over long ranges. The proportion of two- and three-engine turbofan aircraft is relatively small. This mix is typical of airports handling many intercontinental flights--New York J.F. Kennedy Airport, for example.

For a large portion of the study, 100 takeoffs and 100 landings per daytime period for each mix was assumed (i.e. a total of 200 operations per day). For several changes, NEF contours were also calculated with the number of operations, takeoffs and landings for each mix increased to 400 and 1000 per day.*

* The study was not extended beyond 500 takeoffs and 500 landings (1000 operations) since a review of the expected volume of operations per runway at several major airports indicated that a maximum utilization of a single runway for 1975 is unlikely to exceed 1000 operations of the jet powered aircraft considered in our study.

TABLE VI
AIRCRAFT MIX FOR TRADEOFF STUDIES

<u>Aircraft Classification</u>	<u>Mix A</u>	<u>Mix B.</u>
Four-engine Turbojets - Short Range	11%	10%
Four-engine Turbojets - Long Range	1	4
Four-engine Turbofans - Standard Short Range	28	27
Four-engine Turbofans - Standard Long Range	--	22
Four-engine Turbofans - Stretched - Short Range	7	6
Four-engine Turbofans - Stretched - Long Range	--	5
Four-engine Turbofans - Jumbo - Short Range	8	8
Four-engine Turbofans - Jumbo - Long Range	--	8
Two- and Three-engine Turbofans - Standard and Stretched	45	10
Total*	100%	100%

B. Runway Utilization

The shape and size of Noise Exposure Forecast contours under any flight path are also affected by the type of operations (takeoff or landing) as well as the mix of aircraft and volume of operations. Some runways may be used for both takeoff and landing operations and adjacent areas may be exposed to noise from both takeoff and landing operations. Other areas may be exposed to only takeoff noise or only approach noise.

In our study, we considered two runway utilizations, sketched in Fig. 6. For most of the study, we considered "one-way" operations with Runway 1 carrying 100% of the takeoffs and 100% of the landings. However, for several trials, we considered varied operations where Runway 1 carried 67% of the takeoff operations and 67% of the landing operations, while Runway 19 carried the remaining 33% of takeoff and landing operations.

C. NEF Area Calculations

Based upon the runway configurations and aircraft mixes described above, NEF areas were computed for a number of trials. The different trials included baseline operations with no changes introduced, operational changes, changes in aircraft characteristics and combination changes in which changes in operations and changes in aircraft were considered.

For each trial, coordinates for NEF 30 and 40 values were determined by a digital computer. NEF 30 and 40 contours were then determined and the land areas falling within the two contours were computed. In determining the areas, the land around the airport was divided into three sectors as shown in Fig. 6. The takeoff, or north, sector refers to the land area north of the north end of Runway 1-19 i.e. extending beyond 10,000 feet from the start of Runway 1. The landing, or south, sector refers to land areas south of the south end of Runway 1-19. The sideline sector includes areas to either side of the runway as indicated in Fig. 6. For each of the sectors the land areas exposed to NEF values in excess of 30 and in excess of 40 were determined.

Table VII lists for each trial the land areas falling within the NEF 30 and NEF 40 contours for each of the airport sectors. This data provides the basis for the discussion presented in the following section.

TABLE VII
LAND AREAS WITHIN NEF 30 AND NEF 40 CONTOURS

AIRPORT SECTOR¹ AREAS IN SQ. MI.

Trial	Changes ²	R/W Util. ³	Mix ⁴	T.O. (N)		SIDELINE		L (S)	
				NEF 40+	NEF 30+	NEF 40+	NEF 30+	NEF 40+	NEF 30+
1*	None	(a)	A	0.498	4.870	0.996	2.124	0.611	2.989
			B	1.265	7.988	1.080	2.160	0.792	3.739
2	A	(a)	A	0.498	4.027	0.996	2.124	---	---
			B	1.293	12.469	1.077	2.157	---	---
3	A-1	(a)	A	0.498	4.700	0.996	2.124	---	---
			B	1.291	11.922	1.077	2.157	---	---
4	C	(a)	A	---	---	---	---	0.609	2.358
			B	---	---	---	---	0.789	2.836
5	C-1	(a)	A	---	---	---	---	0.609	2.472
			B	---	---	---	---	0.790	2.991
6	D-1	(a)	A	0.277	3.350	0.834	1.927	0.267	1.688
			B	0.758	4.552	0.862	1.864	0.254	1.657
7	D-2	(a)	A	0.256	3.164	0.804	1.895	0.235	1.542
			B	0.672	4.090	0.181	1.808	0.163	1.309
8	A,C-1,D-2	(a)	A	0.256	2.155	0.804	1.895	0.234	1.387
			B	0.665	3.789	0.816	1.803	0.163	1.245
9*	None	(b)	A	0.573	4.194	0.937	2.012	0.602	3.602
			B	1.125	6.393	1.025	2.091	0.960	4.954
10	A,C-1	(b)	A	0.572	3.639	0.937	2.012	0.598	3.117
			B	1.157	8.358	1.023	2.087	0.995	5.210
11	A,C-1,D-2	(b)	A	0.262	2.110	0.723	1.733	0.230	1.789
			B	0.495	2.902	0.730	1.662	0.357	2.122
12	E	(a)	A	0.096	2.426	0.653	1.756	0.206	1.385
			B	0.176	2.245	0.573	1.524	0.116	1.040
13	A,C-1,E	(a)	A	0.096	1.853	0.653	1.756	0.205	1.307
			B	0.176	1.798	0.573	1.524	0.116	1.049
14	A,C-1,E	(b)	A	0.142	1.777	0.594	1.607	0.181	1.575
			B	0.145	1.535	0.510	1.383	0.117	1.309
15	B	(a)	A	0.498	4.192	0.996	2.124	---	---
			B	1.230	8.599	1.077	2.157	---	---
16	B-1	(a)	A	0.498	4.782	0.996	2.124	---	---
			B	1.230	8.340	1.077	2.300	---	---
17	B,C-1,D-2	(a)	A	0.256	2.376	0.804	1.895	0.234	1.387
			B	0.665	3.436	0.816	1.803	0.163	1.245
18	B,C-1,D-2	(b)	A	0.263	2.139	0.725	1.736	0.230	1.803
			B	0.495	2.762	0.730	1.662	0.357	2.076
19	B,C-1,E	(a)	A	0.096	1.852	0.653	1.756	0.205	1.307
			B	0.176	1.786	0.573	1.524	0.116	1.040
20	A,D-1	(a)	A	0.832	1.926	0.304	2.448	---	---
			B	0.858	1.858	0.746	4.976	---	---
21	B,D-1	(a)	A	0.832	1.926	0.304	2.468	---	---
			B	0.858	1.858	0.748	4.072	---	---
22*	---	(a)	A	1.284	2.548	0.964	10.170	1.042	4.548
			B	1.358	2.568	2.084	15.612	1.322	5.497
23*	---	(a)	A	1.738	3.146	2.356	27.186	1.951	7.364
			B	1.798	3.098	4.238	39.684	2.467	8.676
24	B,C-1	(a)	A	1.284	2.548	0.964	7.776	1.036	3.494
			B	1.356	2.564	1.998	16.022	1.270	4.172
25	B,C-1	(a)	A	1.738	3.146	1.964	22.442	1.726	5.356
			B	1.796	3.077	4.126	39.798	2.106	6.320
26	D-1	(a)	A	1.096	2.384	0.634	7.104	0.516	2.682
			B	0.980	2.116	1.066	7.222	0.482	2.690
27	D-1	(a)	A	1.554	2.990	1.604	18.928	1.068	4.644
			B	1.376	2.692	2.166	17.410	1.016	4.686
28	E	(a)	A	0.912	2.216	0.354	5.236	0.394	2.221
			B	0.784	1.914	0.462	4.366	0.240	1.779
29	E	(a)	A	1.374	2.870	1.112	14.158	0.844	3.860
			B	1.150	2.526	1.168	10.578	0.566	3.306

* Baseline - no change introduced

¹See Figure 6

²See Table I for description of changes

³ (a) R/W 1 - 100%
(b) R/W 1 - 67%; R/W 19 - 33%

⁴See Table VI

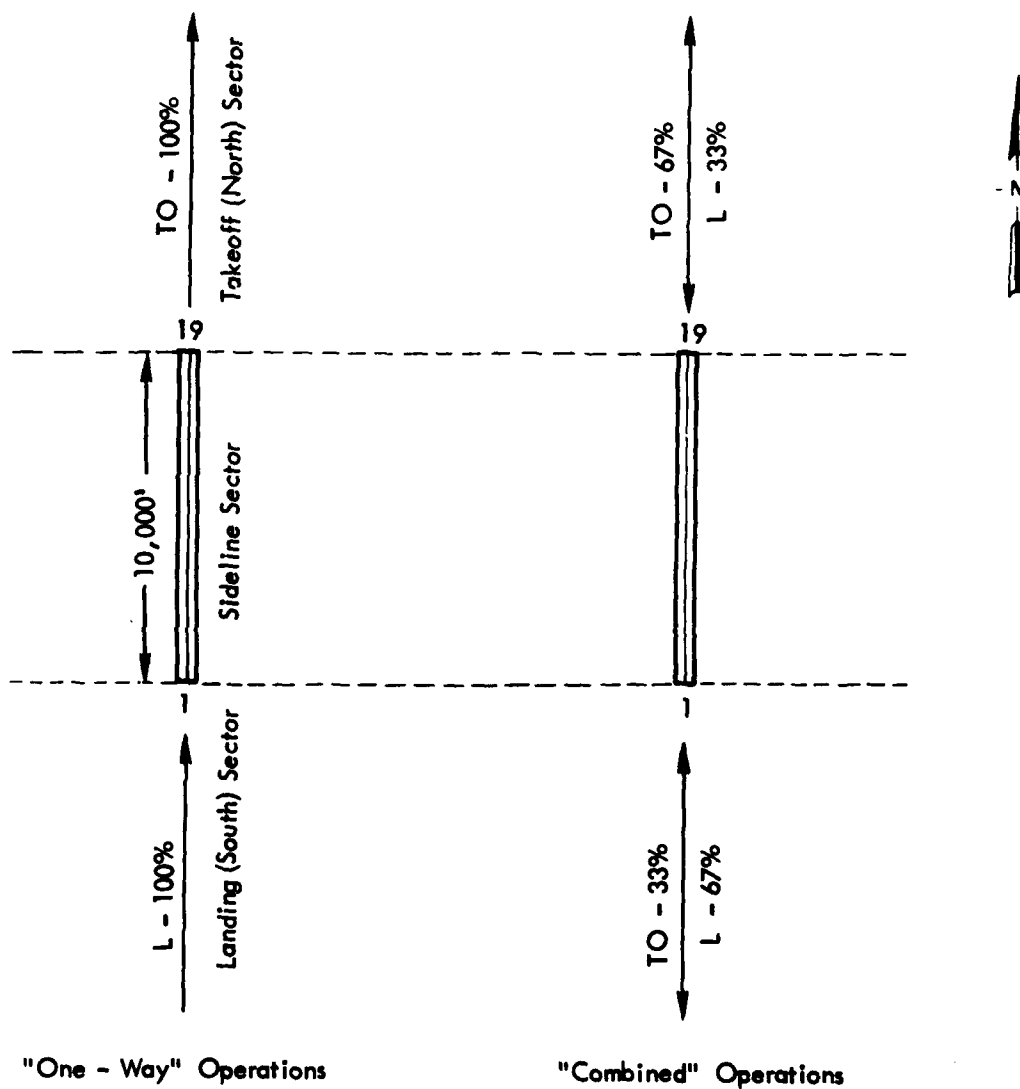


FIGURE 6. SKETCH OF RUNWAY AND FLIGHT PATH CONFIGURATIONS

IV. TRADEOFF STUDY COMPARISONS

Comparisons of the effect of various changes can be made directly using the data provided in Table VII. To facilitate making comparisons in terms of area changes, the data provided for the takeoff (north) and landing (south) sectors have been re-tabulated in Table VIII in terms of percentages. The percentages were computed by taking the baseline NEF areas as 100% and comparing the NEF areas for succeeding changes with respect to the baseline areas. Separate baselines were considered for aircraft Mix A and Mix B.

An example will perhaps make the procedure clearer. Figure 7 shows the NEF contours for Mix A, Trials 1 and 6. Shown in the figure are the areas computed for the land within the NEF 30 and NEF 40 contours. (These are also tabulated in Table VII.) Trial 1 is the baseline reference (no changes); in Trial 6, the retrofit of four-engine turbofan aircraft with lined nacelles (limited effectiveness) has been introduced. If one now compares the area exposed to NEF 30+ values for the takeoff sector (Trial 6) with that for the baseline (Trial 1), one obtains a ratio of 3.35 sq. mi. to 4.87 sq. mi. or 69%. It is this value that is tabulated in the appropriate column of Table VIII.

The percentage changes given in Table VIII are also presented in graphical form in Figs. 8 through 12. Figure 8 shows various land area percentages for the takeoff sector. Separate graphs are shown depicting the relative area changes for NEF 30+ and NEF 40+ land areas. Figure 9 shows a corresponding comparison for the landing sector. Figure 10 shows a comparison for mixed takeoff and landing operations. Figures 11 and 12 compares the percentage changes in takeoff and landing sector land areas for three different total number of operations studied.

A number of comparisons and changes may be noted. A summary of the most pertinent comparisons are tabulated in Table IX. Only the most important ones will be discussed individually.

TABLE VIII
RELATIVE AREAS OF LAND WITHIN NEF CONTOURS FOR
VARIOUS CHANGES IN AIRCRAFT OR OPERATING PROCEDURES

Trial	Changes ³	R/W ⁴ Util. (a)	No. of TO or L	Fig. Ref.	Mix A Many short and intermediate range operations ¹ Airport Sector ²						Mix B Many intercontinental operations ¹ Airport Sector ²					
					N or TO			S or L			N or TO			S or L		
					40+	30-40	30+	40+	30-40	30+	40+	30-40	30+	40+	30-40	30+
1*	None		100		100	100	100	100	100	100	100	100	100	100	100	100
2	A			6	100	81	83	---	---	---	102	161	156	---	---	---
3	A-1			6	100	96	97	---	---	---	102	158	149	---	---	---
4	C			7	---	---	---	99	74	79	---	---	---	99	70	76
5	C-1			7,10	---	---	---	99	78	83	---	---	---	99	75	80
6	D-1			6,7,9,10	56	70	69	44	60	56	60	56	57	32	43	44
7	D-2			6,7	51	66	65	39	55	52	53	51	51	21	34	35
8	A, C-1, D-2			6,7	51	43	44	38	43	46	53	46	47	21	37	33
12	E			6,7,9,10	19	53	50	34	50	46	14	31	28	15	31	28
13	A, C-1, E			6,7	19	40	38	34	46	44	14	24	23	15	32	28
15	B			6,9	100	84	86	---	---	---	97	110	108	---	---	---
16	B-1			6	100	98	98	---	---	---	97	106	104	---	---	---
17	B, C-1, D-2			6	51	48	49	38	49	46	53	41	43	21	37	33
19	B, C-1, E			6	19	40	38	34	46	44	14	24	22	15	31	28
20	A, D-1			6	61	49	50	---	---	---	59	63	62	---	---	---
21	B, D-1			6	61	49	51	---	---	---	59	49	51	---	---	---
9*	None	(b)	100		100	100	100	100	100	100	100	100	100	100	100	100
10	A, C-1			8	100	85	58	99	84	86	103	137	131	104	105	105
11	A, C-1, D-2			8	46	51	50	38	52	50	44	46	45	37	44	43
14	A, C-1, E			8	25	45	42	30	46	44	13	26	24	12	30	26
18	B, C-1, D-2			8	17	48	44	34	52	50	44	43	43	37	43	42
22*	None	(a)	200		100	100	100	100	100	100	100	100	100	100	100	100
24	B, C-1			9,10	100	74	76	99	70	77	96	104	103	96	70	76
26	D-1			9,10	66	70	70	50	62	59	51	46	46	36	53	49
28	E			9,10	37	53	51	38	52	49	22	29	28	18	37	32
23*	None	(a)	500		100	100	100	100	100	100	100	100	100	100	100	100
25	B, C-1			9,10	83	82	83	88	67	73	97	101	100	85	68	73
27	D-1			9,10	68	70	70	55	66	63	51	43	44	41	59	54
29	E			9,10	47	53	52	43	56	52	21	27	27	23	44	38

* Baseline - no changes introduced.
¹ See Table VI for aircraft composition
² See Figure 6
³ See Table I for description of changes.
⁴ (a) - R/W 1-100%
 (b) - R/W 1-67%; R/W 19-33%

TABLE IX
SUMMARY OF SOME COMPARISONS FROM NEF TRADEOFF STUDY

Change*	Path	Land Area NEF 40+	Land Area NEF 30+
A or B	TO	Essentially no effect	Mix A-Moderate decrease when used by all aircraft Mix B-Slight to large <u>increase</u> .
A vs B (Trial 2 vs 15)	TO	Essentially no difference	Mix A-No difference Mix B-6% gradient results in only small <u>increase</u> .
A vs B with retrofits D-1, D-2, E (Trial 20 vs 21; 18 vs 17; 13 vs 19)	TO	Essentially no difference	No difference for E; for D-1 and D-2, cutback for 3% gradient is slightly more effective for Mix A; cutback to 6% gradient is slightly more effective for Mix B.
D-1 or D-2	TO	Substantial reductions - greatest reductions for Mix A	Substantial reductions - greatest reduction for Mix B
D-1 vs D-2 (Trial 6 vs 7)	TO	D-2 slightly more effective - Mix A=5%, Mix B=7%	D-2 slightly more effective - Mix A=4%, Mix B =6%
E	TO	Substantial reductions - greatest reduction for Mix B	Substantial reductions - greatest reduction for Mix B = 22%
E vs D-1 or D-2 (Trial 6 and 7 vs 12)	TO	Change E achieves much greater reduction than D-1 or D-2 - Mix A=66%, Mix B=75%	Change E achieves substantially greater reduction than D-1 or D-2 - Mix A=28%, Mix B=48%
A D-1 (or D-2) vs D-1(or D-2) only. (Trial 20 vs 6; 8 vs 7)		Mix A, slight or no change	Mix A, moderate decrease Mix B, slight decrease for D-2, moderate increase for D-1

TABLE IX (Cont'd)

Change*	Path	Land Area NEF 40+	Land Area NEF 30+
A + E vs E only (Trial 12 vs 13)	TO	No change	Sizable decrease, Mix A = 24% Mix B = 21%
C or C-1	L	Negligible change	Sizable reduction 80%, both mixes
C vs C-1	L	No difference	Change C slightly more effective
D-1 vs D-2	L	Substantial reduc- tion, greatest for Mix B	Substantial reduction greatest for Mix B
D-1 vs D-2	L	Change D-2 moderately more effective, Mix A = 44 vs 39% Mix B = 32 vs 21%	Change D-2 slightly more effective, Mix A = 56 vs 52% Mix B = 44 vs 35%
E	L	Substantial reduc- tion, greatest for Mix B	Substantial reduction, greatest for Mix B
E vs D-2	L	Change E slightly more effective	Change E slightly more effective
C-1 + D-2 vs D-2 only (Trial 8 vs 7)	L	No difference	Slight additional reduc- tion with change C-1, Mix A = 11% Mix B = 6%
C-1 + E vs E only (Trial 13 vs 12)	L	No difference	Very slight additional reduction with change C-1 Mix A = 4% Mix B = 0
A + C-1	TO+ L (mixed)	Little change	Mix A-Substantial reduc- tion Mix B-Moderate to sub- stantial increase
A, C-1 and D-2	TO+ L (mixed)	Substantial reduc- tion	Substantial reduction

TABLE IX (Concluded)

Change*	Path	Land Area NEF 40+	Land Area NEF 30+
A, C-1 and (Trial 1)	TO+ L (mixed)	Very substantial reduction greatest for Mix B	Very substantial reduction, greatest for Mix B
A vs B, with C-1, and D-2 (Trial 18 vs 11)	TO+ L (mixed)	Change B results in moderately greater reduction for Mix A, little difference for Mix B	Very small differences
100 to 500 takeoff, B (Trials 15, 24, 25)	TO	Mix A-Decrease in areas for very large number of operations Mix B-No change	Mix A-Inconsistent changes in effectiveness with number of operations Mix B-Consistent increase in effectiveness with number of operations
D-1 (Trials 6, 26, 27)		Increase in area for large numbers of operations	Mix A-No change Mix B-Increase in area for increasing operations
E (Trials 12, 28, 29)		System increase in relative areas (reduced effectiveness) with number of operations	Very small changes in relative areas with number of operations
100 to 500 landings C-1 (Trials 5, 24, 25)	L	Slight to moderate decrease in relative areas with number of operations	Slight decreases in relative areas with number of operations
D-1 and E (Trials 6, 26, 27; 12, 28, 29)		Consistent moderate decrease in relative areas with number of operations	Consistent moderate decrease in relative areas with number of operations

* See Table I

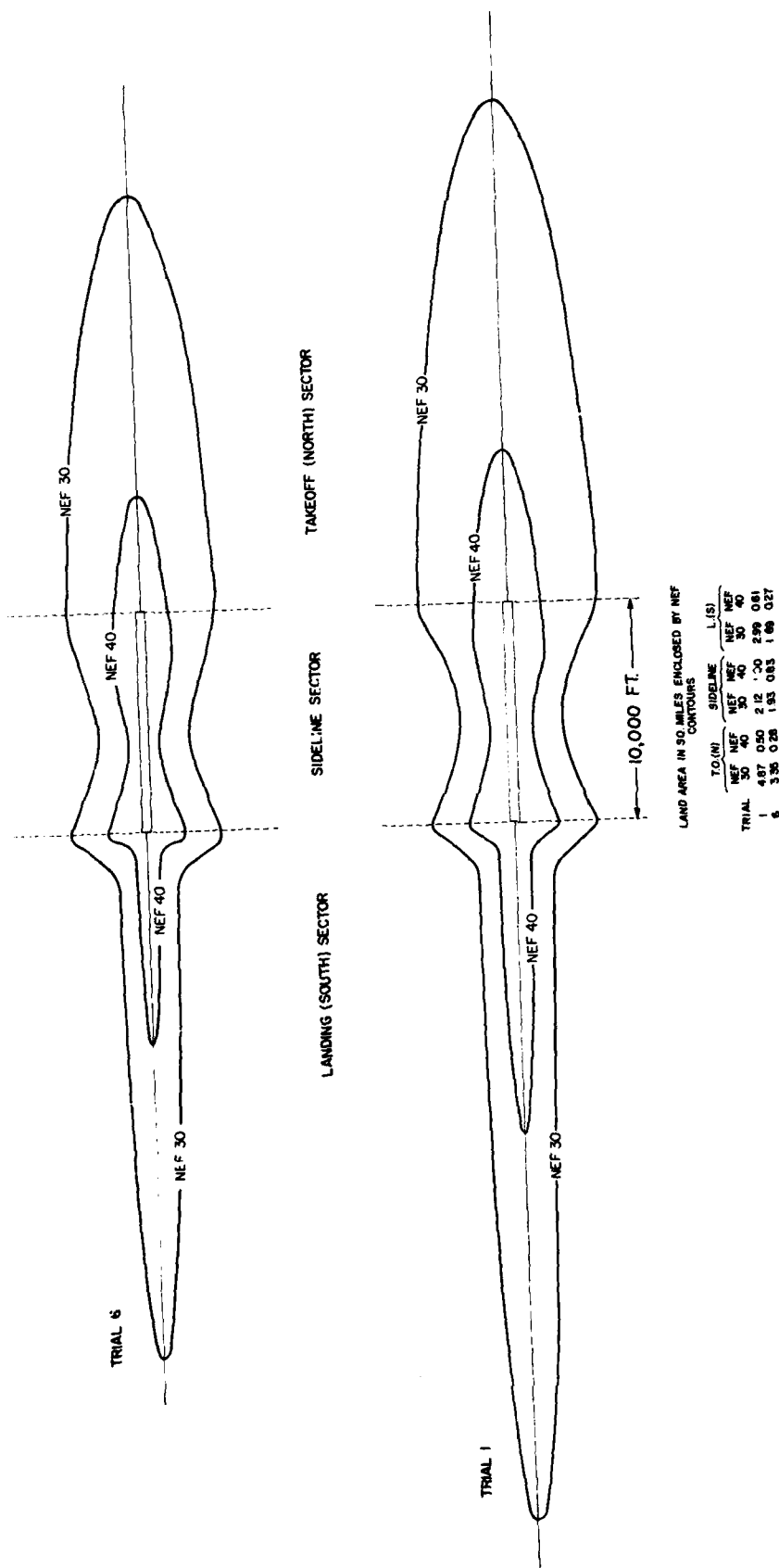


FIGURE 7 SAMPLE OF NEF CONTOURS - AIRCRAFT MIX A

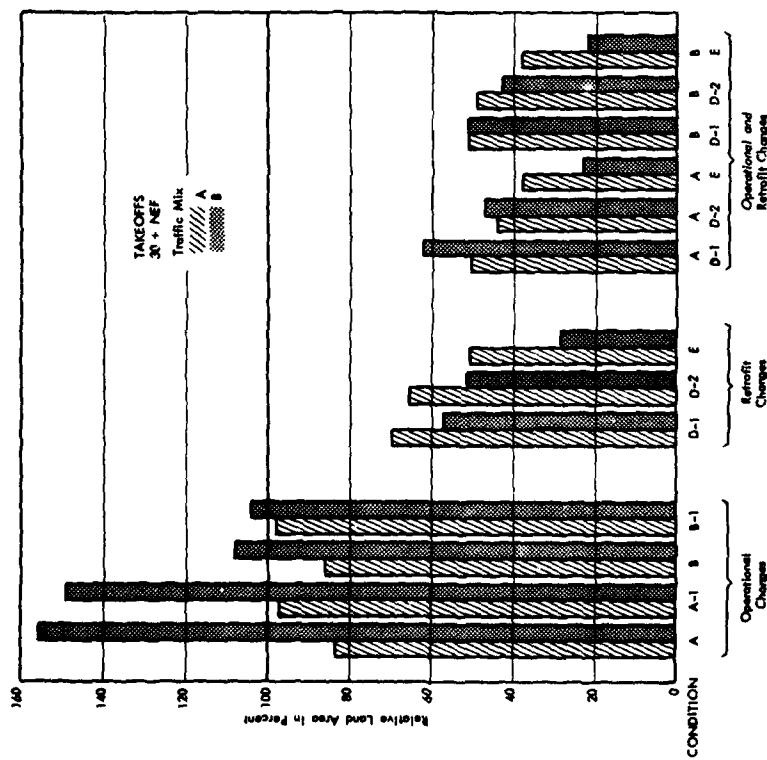
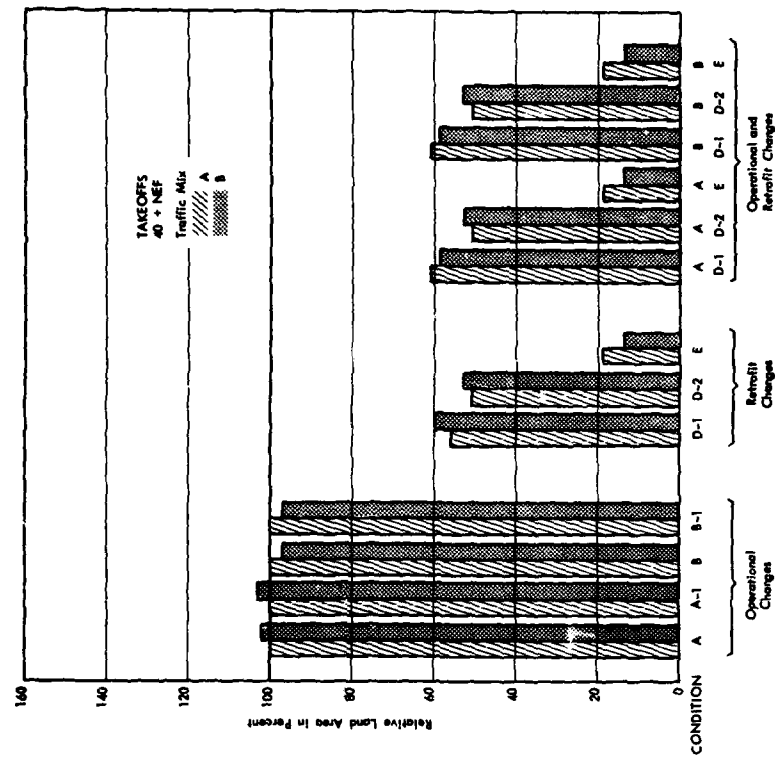


FIGURE 8. RELATIVE LAND AREAS WITHIN NEF 40 CONTOURS - TAKEOFF (NORTH) SECTOR -
100 TAKEOFFS PER DAY

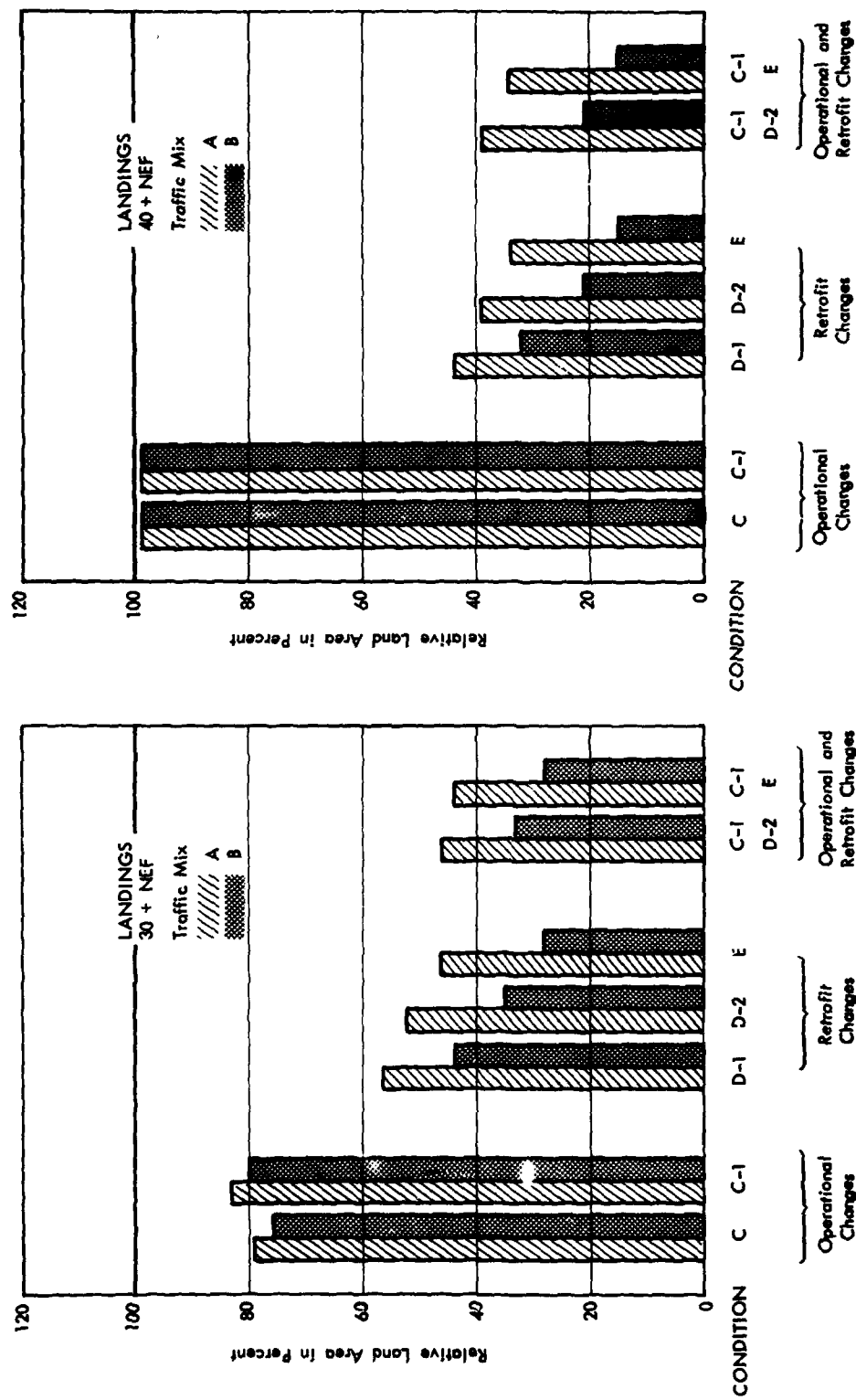


FIGURE 9. RELATIVE LAND AREAS WITHIN NEF 30 AND NEF 40 CONTOURS + LANDING (SOUTH) SECTOR - 100 LANDINGS PER DAY

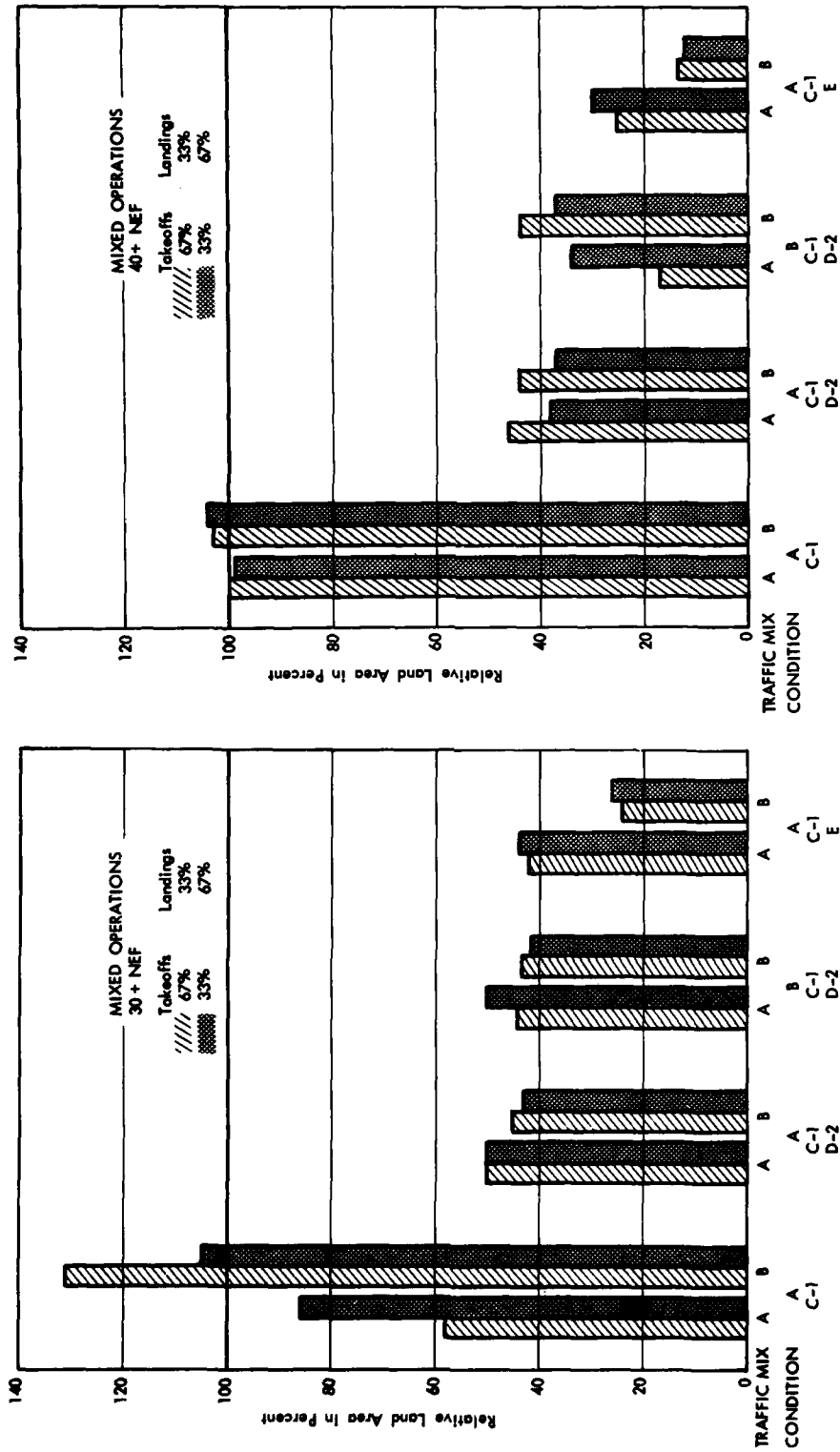


FIGURE 10. RELATIVE LAND AREAS WITHIN NEF 30 AND NEF 40 CONTOURS - COMBINED TAKEOFF AND LANDING OPERATIONS - 100 TAKEOFFS AND 100 LANDINGS PER DAY

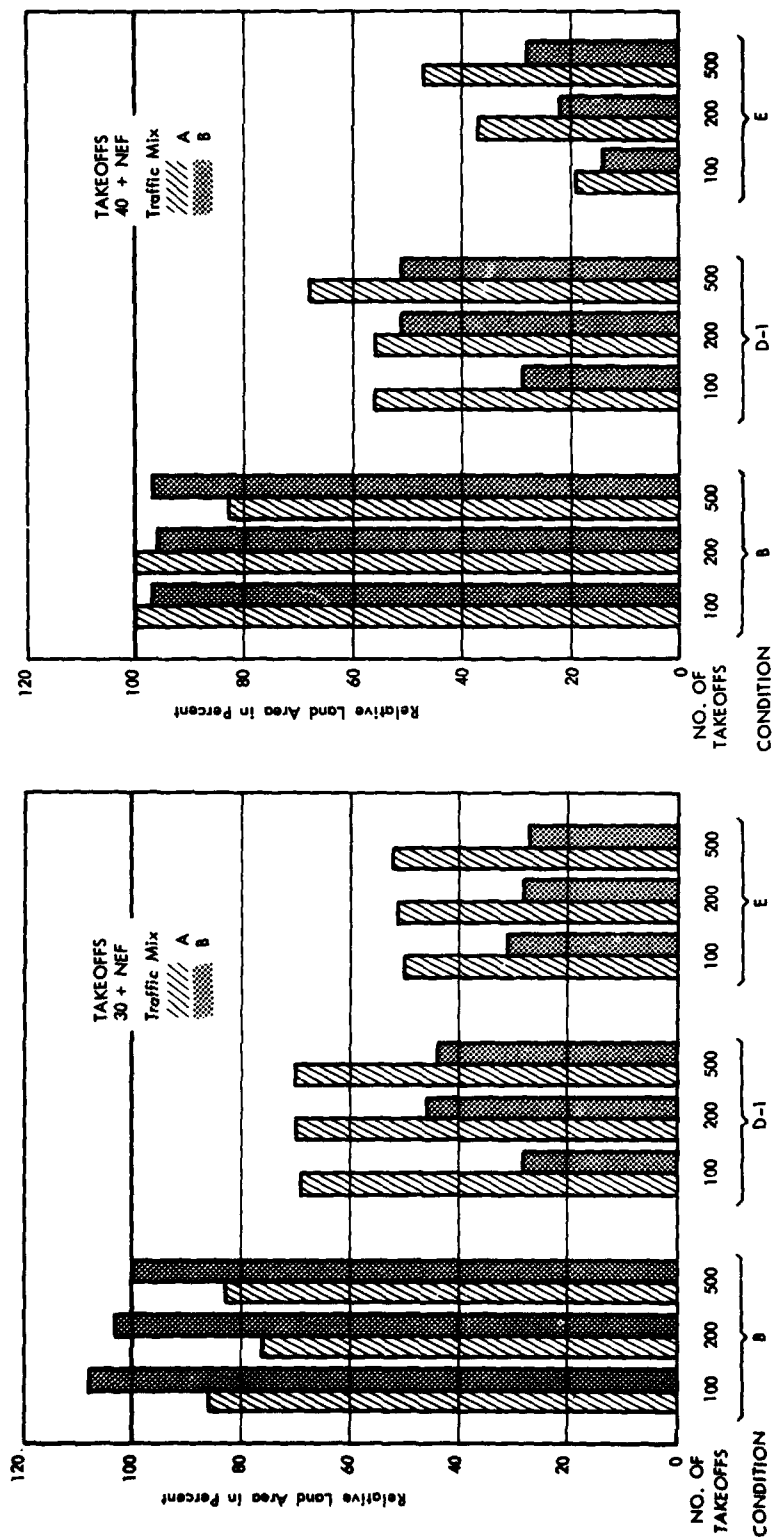


FIGURE 11. RELATIVE LAND AREAS WITHIN NEF 30 AND 40 CONTOURS - TAKEOFF (NORTH) SECTOR - VARIABLE NUMBER OF TAKEOFFS

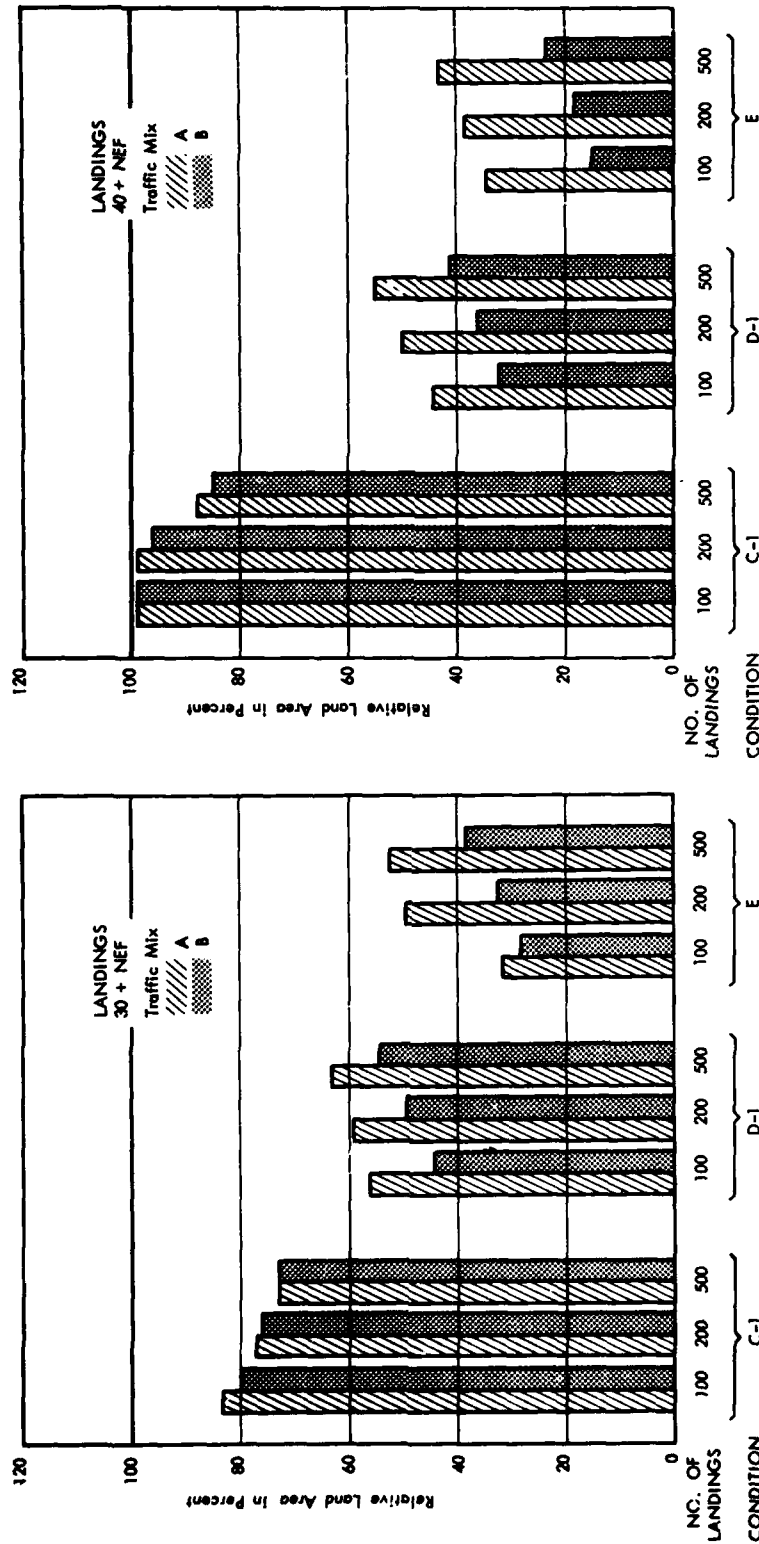


FIGURE 12. RELATIVE LAND AREAS WITHIN NEF 30 AND NEF 40 CONTOURS - LANDING (SOUTH) SECTOR - VARIABLE NUMBER OF LANDINGS

A. Operational Changes

The left-hand sections of Fig. 8 shows the changes resulting from introduction of power cutback to 3% (or 6%) climb gradients upon the takeoff (north) NEF contours. As expected, there is little or no change in the NEF 40+ contour areas since these areas are little affected by a power cutback at 3.5 nautical miles. For the NEF 30 land area, there is a sizable reduction for traffic Mix A but a very significant increase for traffic Mix B. This reflects the very small reduction in noise with a power cutback for most current four-engine turbofan aircraft (aircraft with JT3D engines). In general, the differences in land areas between cutbacks to a 3% or to a 6% climb gradient are relatively small; although it can be noted that a power cutback to a 6% climb gradient reduces the amount of increase in NEF 30+ land areas for traffic Mix B.

The left-hand sections of Fig. 9 indicate the effect of introducing two-segment approaches in the landing (south) segment. There is little change in the NEF 40+ land areas resulting, largely, from the choice of three nautical miles as the point for the transition from the 6° to 3° glide slopes. There is an approximate 20% reduction in the NEF 30+ land areas due to the introduction of two-segment approaches.

An example of the effect of power cutbacks and two-segment approaches on a runway handling both takeoffs and landings may be seen in Fig. 10 (condition A and C-1). There is essentially no change in the NEF 40+ areas. However, there are sizable changes in the NEF 30+ area with significant reductions observed for traffic Mix A and moderate to slight increases with traffic Mix B. This again reflects the limited noise reduction occurring after power cutback for current large four-engine turbofan aircraft.

B. Equipment Changes

The effects on NEF contour areas of introducing lined nacelles, or a "quiet engine" are shown in the middle sectors of Figs. 8, 9 and 10. Examination of Fig. 8 will show the substantial reductions in both the NEF 30+ and NEF 40+ land areas due to the retrofits. The largest reductions are observed for traffic Mix B reflecting the larger proportion of aircraft which would be

directly affected by the retrofits. Comparisons of change D-1 vs D-2 show that there is about 5% difference in land areas for the two degrees (limited and maximum) of nacelle treatment. However, further reductions in areas are evident with the quiet engine installation. (This installation includes not only a further reduction in noise but an improvement in takeoff performance due to the increased thrust assumed for the quiet engine retrofit.) Comparison of the NEF contours under the landing path show very significant reductions due to retrofits.

C. Comparison of Operational And Equipment Changes

The right-hand figure portion of Figs. 8 and 9 show the results of some combined operational and equipment changes. For the NEF 40+ land areas under the takeoff paths, introduction of operational changes, i.e., power cutback, results in little change over the reductions due to equipment changes only. However, the NEF 30+ land areas show substantial reductions (15 to 20%) with traffic Mix A when power cutback procedures are introduced. There is, however only moderate change (except for the quiet engine retrofit) for traffic Mix B when power cutback procedures are introduced.

The right-hand portion of Fig. 9 shows the effects under the landing segment. Similarly, there is little change in the NEF 40+ land areas but some slight reductions in the NEF 30+ area when a two-segment approach is introduced for a fleet equipped with four-engine turbofan aircraft with either lined nacelles or "quiet" engines.

For mixed takeoff and landing operations, some comparisons are shown in Fig. 10. One may note, among other things, that there is less reduction in land area for a cutback to 3% than for a 6% climb gradient, with aircraft retrofitted with lined nacelles.

D. Variations With Total Number of Operations

Figures 11 and 12 show the relative land areas within NEF 30 and 40 zones taking as baseline references 100, 200 and 500 landings and takeoffs per day (i.e. 200, 400 and 1000 operations per day). As shown in the figure, the relative effectiveness of the various noise reduction changes vary somewhat with number of operations. To further indicate this, Fig. 13 shows the land areas in the takeoff sector falling within the NEF 30 and 40

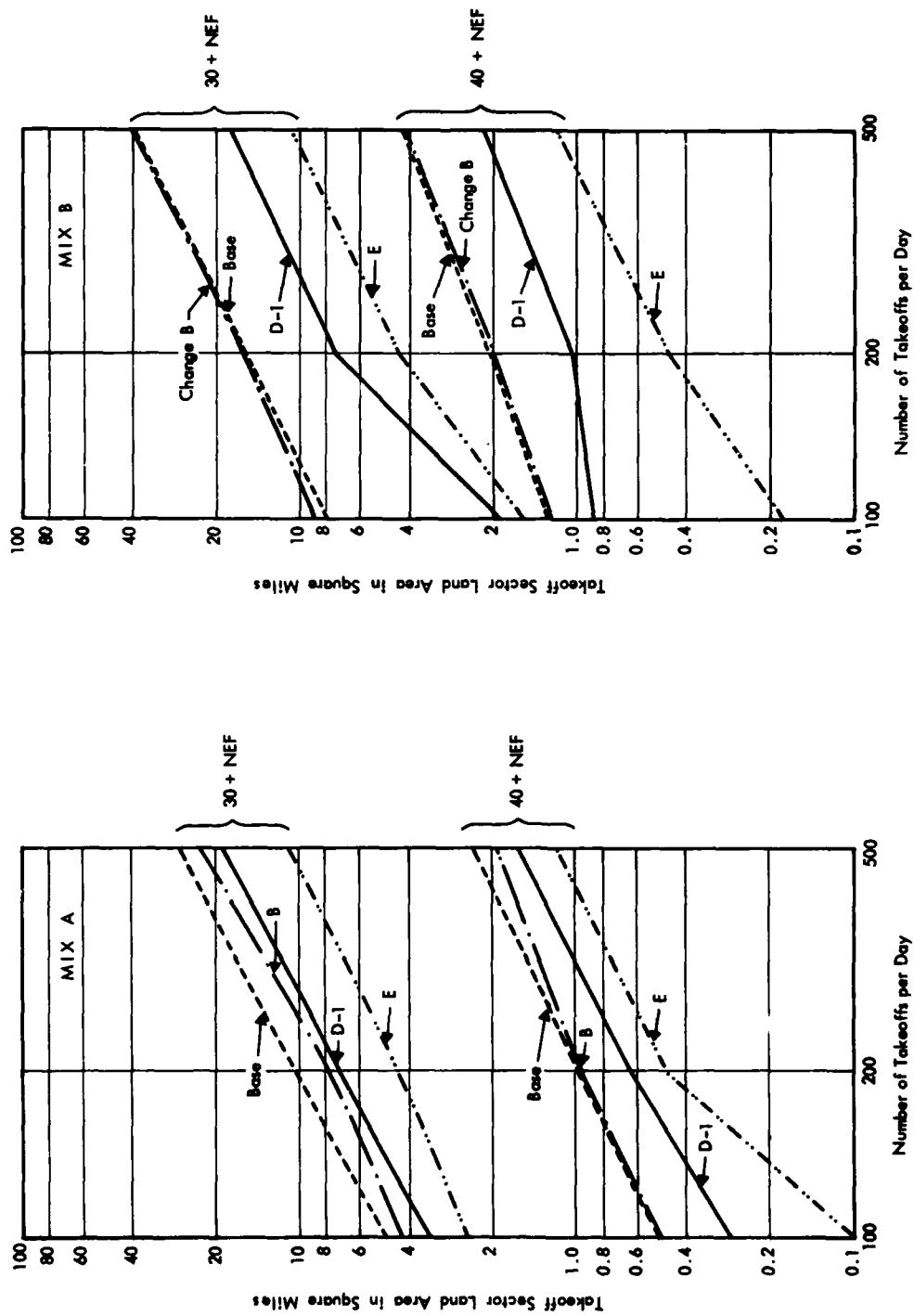


FIGURE 13. VARIATION IN TAKEOFF SECTOR LAND AREAS WITHIN NEF 30 AND NEF 40 CONTOURS WITH NUMBER OF TAKEOFFS

contours plotted as a function of the number of takeoffs per day. (Both areas and numbers of operations are plotted on logarithmic scales in Fig. 13.) The fact that the curves are broken and are not parallel indicates some variation in effectiveness of the changes with number of operations. However although there is some variability with volume of operations, the relative ranking of the effectiveness of various changes is quite consistent and generally remains unchanged as the number of operations is varied.

With operational changes only (power cutback and/or two segment approaches) there is a general trend toward increased effectiveness with an increase in number of operations. For retrofit with either lined nacelles or quiet engine retrofit applied to four-engine turbofan aircraft, there is a general trend toward slightly less effectiveness as the number of operations is increased.

The relative effectiveness of the various noise reduction changes is influenced by the number of operations for a number of reasons. The aircraft takeoff profiles are not the same for different aircraft classifications and the EPNL curves for the different aircraft classifications are not parallel, hence the importance of a given class of aircraft in determining a given NEF value may slowly change with the number of operations.

For segmented takeoff or landing profiles, such as the power cutback after takeoff (or the two segment approach), the choice of the distance at which the power cutback (or change in glide slope angles) is made will influence the shape of a curve showing the relative effectiveness of the change vs. number of operations. For example, with only small number of operations, the NEF 40 contour may well close before the 3.5 nautical miles power cutback point is reached, hence the land area within the NEF 40 contour would not be affected by the power cutback procedure. However as the number of operations is increased, the NEF 40 contour would close at a point beyond the point at which the power cutback becomes effective. In this case portions of the area included within the NEF 40 contour would be influenced by the power cutback. Further increases in number of operations would include more and more land within the NEF 40 contour which would be affected by the power cutback.

E. Major Trends

An important trend denoted by the results discussed above is the significant reduction in land areas exposed to NEF 30 or 40+ noise environment by the introduction of either lined nacelles or the quiet engines. On the other hand, operational changes alone generally result in less substantial reduction (and even some increases) in land areas.*

With retrofits of the current four-engine turbofan fleet, the largest reductions in land areas result from the introduction of power cutback or two-segment approaches.

While the arbitrariness of the boundaries used in this study limit the direct application of the results of this study to any particular airport, the major trends (such as the significant reduction in NEF contours due to introduction of lined nacelles or a quiet engine) would likely be very apparent in any airport handling a sizable proportion of four-engine turbofan aircraft. It should also be pointed out that retrofits applied to two- and three-engine turbofan aircraft, as well as four-engine turbofan aircraft, would result in a further shrinkage of the land areas within the NEF 40 and 30 land areas.

* Although not specifically discussed above, but clearly evident from study of Table VII, a shrinkage of sideline NEF boundaries also results from introduction of quieter aircraft (lined nacelles or "quiet" engine retrofit), but operational changes alone will produce no change in the sideline sector NEF boundaries.

REFERENCES

1. D.E. Bishop, R.D. Horonjeff, "Procedures for Developing Noise Exposure Forecast Areas for Aircraft Flight Operations," FAA Report DS-67-10, August 1967.
2. SAE Research Committee R2.5 "Technique for Developing Noise Exposure Forecasts," FAA Report DS-67-14, August 1967.
3. Based on interpretation of information contained in Letter, Reference 2532, from F.J. Montegani, Lewis Research Center, NASA to D.E. Bishop, dated 31 July 1968.
4. W.C. Sperry, "Aircraft Noise Evaluation," FAA Report NO-68-34, September 1968.

APPENDIX

SUMMARY OF BASIC NOISE EXPOSURE FORECAST EQUATIONS

In calculation of NEF values, aircraft noise levels are expressed in terms of the effective perceived noise level (EPNL) as defined in reference 4. In estimating the noise exposure near an airport or flight path resulting from the operation of a number of different aircraft, it is convenient to group the aircraft in classes based upon consideration of the aircraft noise characteristics and takeoff and landing performance. Each class is assigned a description of the noise in terms of a set of EPNL vs. distance curves and a set of takeoff and landing profiles. Thus, for a given class of aircraft at a particular power setting (i.e. takeoff power) it is assumed that the aircraft noise characteristics may be described by a single EPNL vs. distance curve.

The total noise exposure produced by aircraft operations at a given point is viewed as being composed of the effective perceived noise levels produced by different aircraft classes flying along different flight paths. For aircraft class i on flight path j , the NEF (ij) can be expressed as

$$NEF (ij) = EPNL (ij) + 10 \log \left[\frac{N (day) (ij)}{K (day)} + \frac{N (night) (ij)}{K (night)} \right] - C$$

where (Eq. 1)

NEF (ij) = Noise Exposure Forecast value produced by aircraft class (i) along flight path segment (j).

EPNL (ij) = Effective perceived noise level produced at the given point by aircraft class (i) flying along flight path segment (j)

K = Constant normalizing the adjustment in NEF values due to volume of operations. Different values of K are used for daytime and nighttime movements.

C = Arbitrary normalization constant.

K (day) is chosen so that for 20 movements of a given aircraft class per daytime period, the adjustment for number of operations is zero. Hence,

$$10 \log \frac{20}{K(\text{day})} = 0 \quad K(\text{day}) = 20$$

K (night) is chosen such that for the same average number of operations per hour during daytime or nighttime periods the NEF value for nighttime operations would be 10 units higher than for daytime operation. Hence,

$$10 = 10 \log \frac{K(\text{day})}{K(\text{night})} \therefore \frac{9}{15}$$

where 9 and 15 are the number of hours in the nighttime and daytime periods respectively.

$$\text{And, } K(\text{night}) = 1.2$$

The value assigned to C is 75. Choice of this value is based upon two considerations.

First, it is desirable that the number assigned to the NEF values be distinctly different in magnitude from the effective perceived noise level so that there is little likelihood of confusing effective perceived noise levels with NEF values. A second aspect is the desirability of selecting a normalization factor that will roughly indicate the size of the NEF value above some threshold value, indicating the emergence of the noise exposure from levels which would have little or no influence on most types of land usage.

With the above choices for values of K and C, Eq. (1) becomes:

$$\begin{aligned} \text{NEF}(ij) &= \text{EPNL}(ij) \\ &+ 10 \log [N(\text{day})(ij) + 16.67 N(\text{night})(ij)] - 88 \end{aligned}$$

(Eq. 2)

For only daytime operations, as assumed for the cases studied in this report, Eq. 2 becomes simply:

$$NEF (1j) = EPNL (1j) + 10 \log [N (day) (1j)] - 88$$

(Eq. 2a)

The total NEF at the given ground position may be determined by summation of all the individual NEF (1j) values on an "energy" basis:

$$NEF = 10 \log \left[\sum_i \sum_j \text{antilog} \frac{NEF (1j)}{10} \right]$$

(Eq. 3)